

**Understanding Air-Sea Coupling Processes and Coupled Model Predictions Using  
GOTEX Measurements and COAMPS/NCOM  
and  
Aircraft Measurements for Understanding Air-Sea Coupling and Improving  
Coupled Model Predictions**

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**LONG-TERM GOAL**

The long-term goal of this project is to improve physical parameterizations of the coupled model.

**OBJECTIVES**

The NPS project has two components, one is to use previous aircraft measurements from the Gulf of Tehuantepec (GoT) and the coupled COAMPS/NCOM to examine air-sea coupling processes and the performance of the coupled model; the other is to obtain new measurements with the NOAA P-3 over the Indian Ocean as part of the Dynamics of the Madden-Julian Oscillation (DYNAMO) and ONR Litterol Littoral Air-Sea Processes (LASP) DRI. The objectives of the GOTEX-related project are to explore the coupled atmospheric boundary layer and upper ocean processes through in-depth data analyses of GOTEX (Gulf of Tehuantepec Experiment) measurements to improve our understanding of the small-scale spatial and temporal variability within the atmospheric boundary layer (ABL) and the ocean mixed layer (OML) in the gap outflow region, to determine the feedback process and the dominant mechanisms for cooling of SST within the Gulf of Tehuantepec (GoT), and to explore the simulated atmospheric and oceanic responses to the gap outflow events using the coupled COAMPS/NCOMS. The objectives of DYNAMO/LASP project were to address the basic science questions/hypotheses regarding air-sea interaction and tropical convection with the unique standalone suite of measurements on the NOAA WP-3D for concurrent atmosphere and oceanic sampling, and to bridge observations from fixed locations on ships and islands.

The objectives of the NRL project are to obtain vertical profiles of the solar and IR irradiance throughout the atmospheric column in order to characterize the evolution of the solar and IR heating/cooling rate profiles for an MJO cycle. Also, to use the measured solar/IR irradiance profiles as input to, and validation of, the Navy's coupled ocean/atmosphere model, COAMPS.

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## **APPROACH**

Both NPS studies involved aircraft measurements. The GOTEX project included analyses of aircraft measurements of the atmospheric and oceanic boundary layers and simulations of a two-way coupled ocean-atmosphere mesoscale model. Our work within this project consists of three parts: a comprehensive analyses of GOTEX measurements, analyses of the coupled COAMPS/NCOM simulated gap outflow events, and evaluation of the coupled model results using GOTEX measurements. The measurements of GOTEX were based on the NCAR C-130 in central Mexico in January/February 2004. Simulations of the stand-alone COAMPS V. 5, the stand-alone NCOM V. 4, and the fully-coupled COAMPS/NCOM models were provided by NRL Monterey. For the DYNAMO/LASP project, field deployment and its preparation and post-field analyses were our major efforts.

On the NRL project, identical pairs of customized pyranometers and pyrgeometers were mounted on the top and bottom of the NOAA P-3 aircraft to directly measure the down- and up-welling solar and infrared irradiance at multiple altitudes throughout the atmospheric column. These instruments were commercially available solar and IR radiometers modified for aircraft use. In addition, vertical profiles of the thermodynamic properties of the atmosphere (temperature, pressure, relative humidity, winds, etc) obtained from dropsondes released from the NOAA P-3 aircraft will be used as input to a radiative transfer model to derive the solar/IR heating/cooling rate profiles for the various phases of the MJO cycle.

Qing Wang is responsible for the overall project. GOTEX related work was mainly performed by LCDR Heather Hornick, who worked on analyses of aircraft data and coupled and uncoupled model simulations as part of her Ph. D thesis. Coupled and uncoupled model simulations were made at the Naval Research Laboratory, Monterey, CA by Drs. X. Hong and S. Wang.

Qing Wang is the lead PI for the NOAA WP-3D DYNAMO/LASP project who was responsible for organizing and drafting P-3 operation plan, P-3 field measurements, and post-field analyses. Data analyses of P-3 also involves NPS MS and Ph. D students and NPS contractors.

## **WORK COMPLETED**

Some of the preliminary data analyses of the GOTEX aircraft data were made in FY11. Our work on this project in FY12 pushed these analyses forward for a comprehensive understanding of the boundary layer and upper ocean evolution by focusing on two well-sampled cases during GOTEX. Meanwhile, work in FY12 also focused on analyses of the coupled COAMPS/NCOMS results to augment the understanding of the coupled evolution seen from aircraft observations and on evaluation of coupled model performance in simulating gap outflow events with the focus on boundary layer and upper ocean processes.

DYNAMO/LASP related work are all related to the 2011 field campaign and the post-analyses.

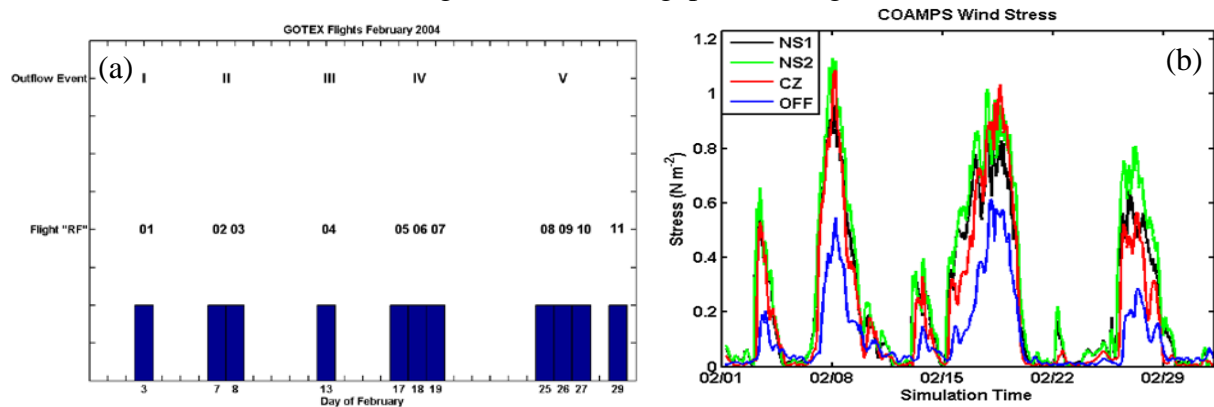
Specific work done includes:

1. Evaluated downstream atmospheric boundary layer development using a combination of aircraft sounding and dropsonde soundings, particularly for two gap events (Events II and V) consisting of five flights.

2. Examined downstream upper ocean evolution under the gap flow using all AXBT measurements from GOTEX.
3. Use aircraft in situ measurements from level legs to examine the temporal and spatial variation of mean and turbulent quantities at different stages of the gap outflow.
4. Examined the simulated atmospheric and oceanic boundary layers from coupled and uncoupled COAMPS/NCOM simulations.
5. Using GOTEX aircraft measurements to evaluate the coupled and uncoupled model performance. Comparison of the two model setup reveals area of improvements using the coupled model for the gap outflow cases.
6. Drafting of the P-3 operational plan for DYNAMO/LASP field campaign and arranging for all logistics for P-3 operation to be based on Diego Garcia including shipping, receiving, and storing of all P-3 PI equipment/tools, arranging for Diego Garcia DYNAMO/LASP operational office and local support.
7. P-3 field deployment from Diego Garcia. A total of 12 flights were made with 486 dropsonde profiles for the lower atmosphere and 395 AXBT/AXCTD profiles for the upper ocean in addition to flight level data.
8. Extensive data QC for all AXCTD drops and some AXBT drops. Second round of data QC is still on-going.
9. Analyses of upper ocean characteristics using AXBT/AXCTD profiles.
10. Analyses of DYNAMO/LASP aircraft data on boundary layer variability under convection and non-convection conditions in different phases of MJO.
11. The customized solar and IR radiometers were mounted on the NOAA P-3 aircraft and successfully measured the down- and up-welling solar and infrared irradiance on the majority of the flights during DYNAMO. These radiometers were calibrated both pre- and post-mission at the CIRPAS Radiometer Calibration Lab. Work is in progress on the quality-control of this dataset and the further analysis to generate measured heating/cooling rate profiles. Work has also begun on incorporating the dropsonde data into the radiative transfer model to generate model-derived heating/cooling rates (NRL effort).

## RESULTS

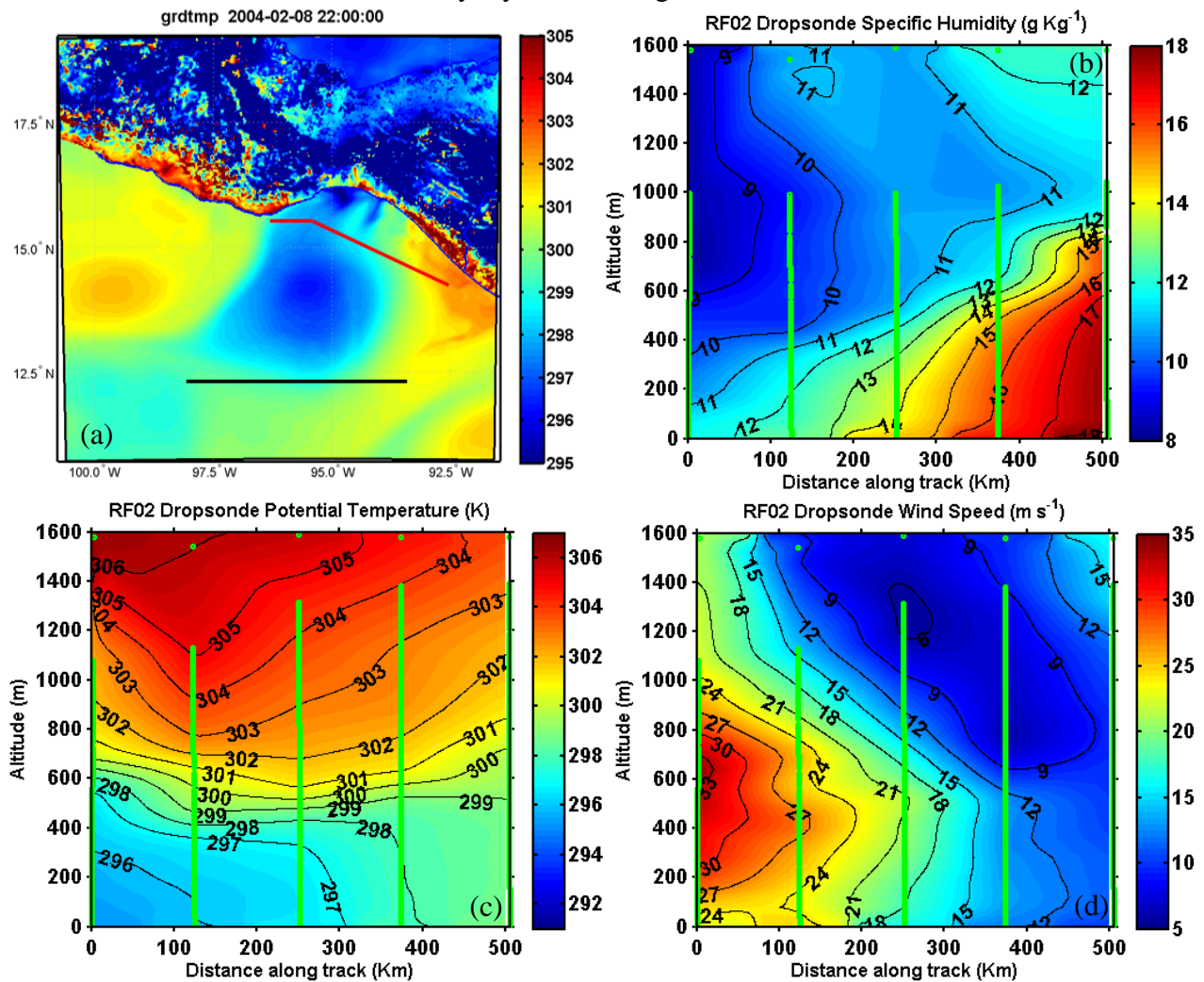
***Downstream evolution of atmospheric and oceanic boundary layers:*** GOTEX measurements consist of 11 research flights that covered five gap wind events in the month of February 2004. Figure 1 below shows the time of all 11 flights and the five gap events together with the simulated wind stress



**Figure 1. (a) Summary of date, flight number, and event number for all GOTEX flights; (b) Time variation of COAMPS surface wind stress at different downstream locations of the**

*outflow: NS1 and NS2 are in the nearshore region, CZ represents the coupling zone, and OFF represents the offshore region.*

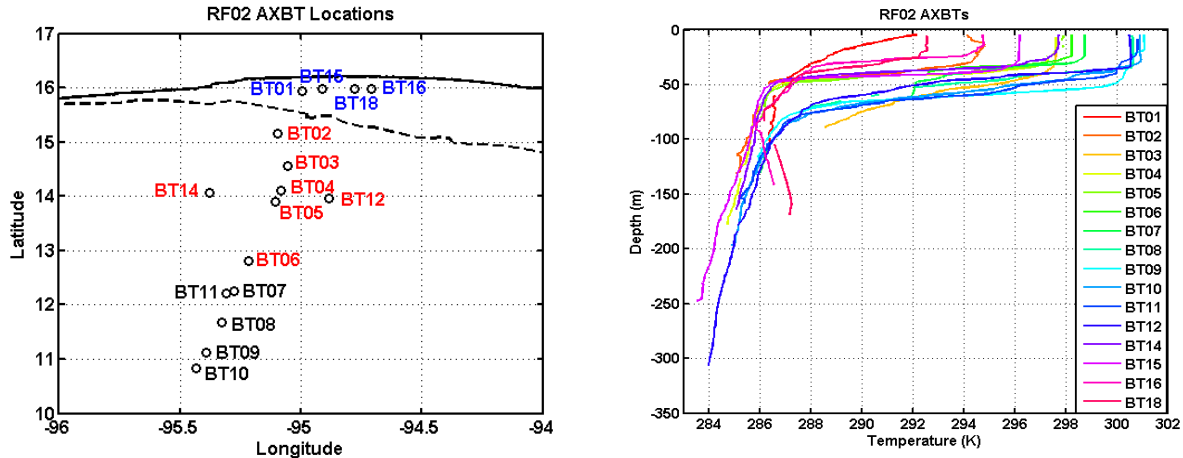
from coupled COAMPS/NCOMS that best depicts the intensity of each event. We have analyzed data from all flights and decided to focus on events II and V, consist of five flights, for in-depth case analyses. Both events were chosen because of the good spatial and temporal coverage of the C-130 measurements with sufficient combination of soundings, level legs, dropsondes and AXBT profiles. Event II was brief and strong, while event V was moderately strong and lasted longer. Two research flights were made in both events, while one flight (RF08) was also made prior to the onset of Event V, providing us with the pre-gap wind condition. Based on a careful review of the nine successful GOTEX flights, the outflow area was divided into three regions based on the oceanic response to the gap wind forcing. The Nearshore region, shoreward of the 500 m bathymetry curve, responded quickly to the influence of the gap outflow. During the first flight of each event, this region was the location of the coldest, driest boundary layer air, strongest winds and surface wind stress.



*Figure 2. (a) surface temperature from coupled COAMPS/NCOM simulations showing the separation of the three regions based on oceanic response to the gap outflow; (b)-(d) downstream evolution of specific humidity, potential temperature, and wind speed from dropsonde measurements during the first flight of event II (RF02).*

The Coupling Zone region begins at the 500 m bathymetry contour where the bottom begins to slope sharply down to the deep Middle America Trench and continues to the furthest offshore extent of measured sea-surface temperature cooling. During the first flight, the wind speed, wind stress, and TKE were slightly lower than within the Nearshore region. However, during the second flight, the strongest winds, highest wind stress and TKE were within the Coupling Zone, suggesting that during the decay stage of the outflow event, the strongest forcing on the upper-ocean was within this region. Boundary layer air within this region warmed from the Nearshore to the Coupling Zone, but was cooler during the second flight. Sea-surface temperatures also cooled significantly within the Coupling Zone negative sensible heat flux between outflow events. The gap outflow events induced even more cooling of the OML. In general, the Coupling Zone sea-surface temperatures did not cool as much as within the Nearshore region, but did continue to cool from the first to the second flight.

The ocean response was minimal in the Offshore region, while the atmospheric boundary layer was warmer and more moist than the other two regions, with much less spatial variability. Northerly winds continued to flow through this region, with wind speed weakening with distance offshore. Figure 2a illustrates the coupled COAMPS/NCOM simulated SST variations and the separation of the three regions. Figures 2b-2d show the evolution of temperature, humidity, and wind speed along the outflow jet core sampled by dropsondes from RF02. Figure 3 shows the downwind evolution of the upper ocean temperature profiles from the same flight. It is seen that the upper ocean temperature difference between the Nearshore and Offshore regions is about 9°C during the development stage of this outflow event. It is also noticed that the sharpest thermocline temperature gradients are in the Coupling Zone, suggesting stronger upwelling in that region.

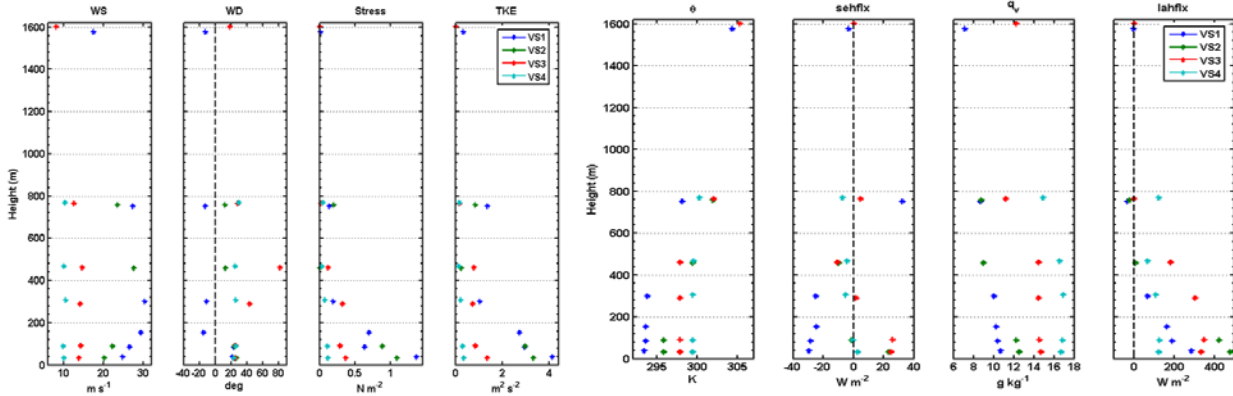


**Figure 3. (a) AXBT locations from RF02;(b) Upper ocean temperature profiles corresponding to all AXBT drops in (a).**

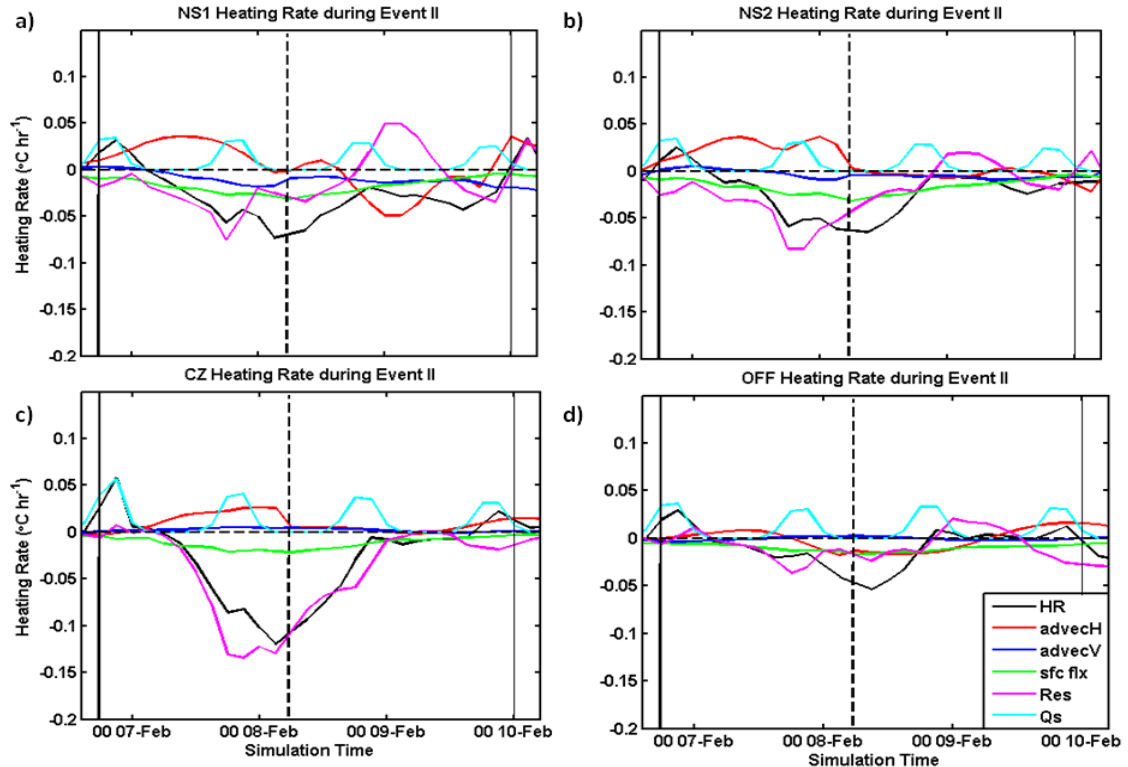
**Mean and turbulence characteristics in different regions gap outflow:** During GOTEX, multiple stacks of level legs were made at different distance from the gap along the jet core. These stacks of measurements were used to calculate profiles of mean and turbulence profiles in the three response regions. An example from RF02 is shown in Fig. 4. Here, VS1 and VS2 were made in the Nearshore and Coupling Zone, respectively. VS3 and VS4 were both made in the Offshore region. The mean temperature, specific humidity, and wind profiles are consistent with dropsonde and/or aircraft soundings. Figure 4 shows that the low-level turbulence kinetic energy (TKE) is the strongest in the NS region and decrease towards Offshore in concert with the magnitude of wind stress. Sensible heat flux is negative in the Nearshore region, suggesting stable stratification in this region, and positive in the Coupling Zone and the adjacent Offshore region, and became neutrally stratified in the far Offshore

region. Significant positive latent heat flux was measured in all regions, although the maximum are seen in the vicinity of the Coupling Zone. These results suggest significantly different upper ocean forcing in all regions and even within one region.

Using the measurements shown in Fig. 4, we are able to make budget analyses for the mean variables, such as specific humidity. Such analyses suggest that the Nearshore and Coupling Zone regions should have seen significant moistening from the turbulence flux convergence. This moistening, at 24 and 31  $\text{g kg}^{-1} \text{ day}^{-1}$  for VS1 and VS2, respectively, is largely balanced by drying through advection, which averages to approximately  $-26 \text{ g kg}^{-1} \text{ day}^{-1}$ . Thus, dry air advection and turbulent mixing are the two dominant processes, with opposite sign and similar magnitude. Therefore, we do not expect significant variation of boundary layer moisture with time during the gap outflow event, which is confirmed by the C-130 measurements on the following day.



**Figure 4.** Mean, TKE, and turbulence stress, sensible heat flux and latent heat flux from stacks of level legs along the outflow trajectory.

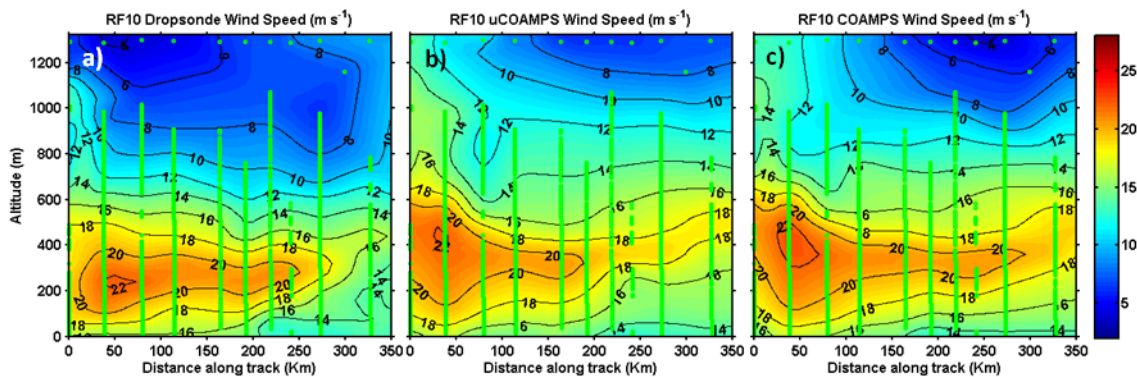




**Figure 5. Time variation of heating rate (black), horizontal advection (red), vertical advection (blue), surface flux heating (green), residual heating (pink) and solar radiation heating (cyan) in  $^{\circ}\text{C hr}^{-1}$  for a) NS1, b) NS2, c) CZ, and d) OFF from 12 UTC on 06 February to 03 UTC on 10 February 2004. The residual term includes entrainment and errors in the budget calculations.**

**Mechanisms of upper ocean temperature evolution from coupled COAMPS/NCOM:** One of the basic questions this research intended to answer is what are the dominant physical processes controlling the evolution of the upper ocean temperature. This question was approached using the results of NCOM through the coupled model setting and the results of the upper ocean heat budget terms are shown in Fig. 5. Calculations of the ocean mixed layer heat budget from the coupled NCOM simulations indicated that entrainment mixing at the base of the mixed layer is the dominant mechanism for cooling of the sea-surface temperatures. Loss of heat due to upward heat flux also contributes to cooling. Closest to the coast, upwelling from divergence caused by offshore flow provides additional cooling; such effects are minimum in the coupling zone and the offshore regions. The time variation of the heat budget terms suggests different recovery time periods for each of the identified outflow regions.

**COAMPS/NCOM evaluation using GOTEX measurements:** Previous modeling studies of the Gulf of Tehuantepec have used stand-alone atmosphere or ocean models only (e.g., Steenburgh et al. 1998; McCreary et al. 1989). These studies have hypothesized that a fully-coupled model study of the gap outflow would be beneficial. Observations from the GOTEX experiment provide the opportunity for model evaluation with measurements in the atmosphere, the upper-ocean, and particularly turbulence near the air-sea interface for quantifying the air-sea exchange processes.



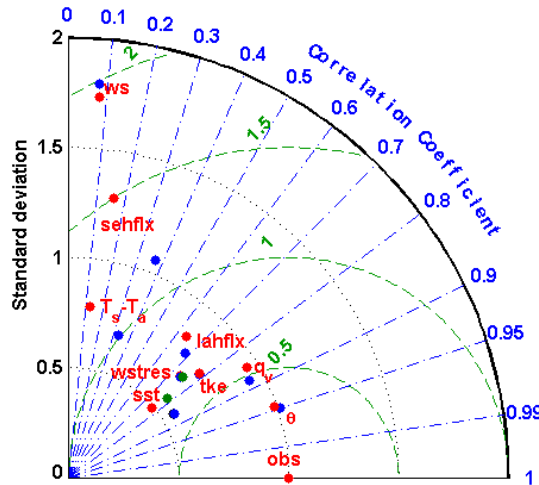
**Figure 6. Wind speed ( $\text{m s}^{-1}$ ) cross sections along the RF10 flight track for a) dropsondes, b) uncoupled COAMPS, and c) coupled COAMPS/NCOM. Green vertical lines represent the locations where the dropsonde data were available. The horizontal axis shows the distance along the track in kilometers from about 4 km from shore**

Figure 6 shows a subjective evaluation of the wind speed simulated by the stand alone COAMPS and the coupled COAMPS against dropsonde measurements during the second flight of Event V. Here, agreement of the wind speed maximum is clearly seen along with the narrow, elevated structure of strongest winds reaching offshore. The elevation of the jet is higher in both the uncoupled and coupled COAMPS output and the simulated depth of the strongest winds is greater than measured by the dropsondes. In the uncoupled simulation, the strongest winds (greater than  $20 \text{ m s}^{-1}$ ) do not reach far enough offshore, compared with the observations, while the coupled COAMPS wind jet reaches farther offshore than the observations. Comparisons from other GOTEX flights show similar results to those in Fig. 6. In general, during each event, the modeled outflow jet was in reasonable agreement



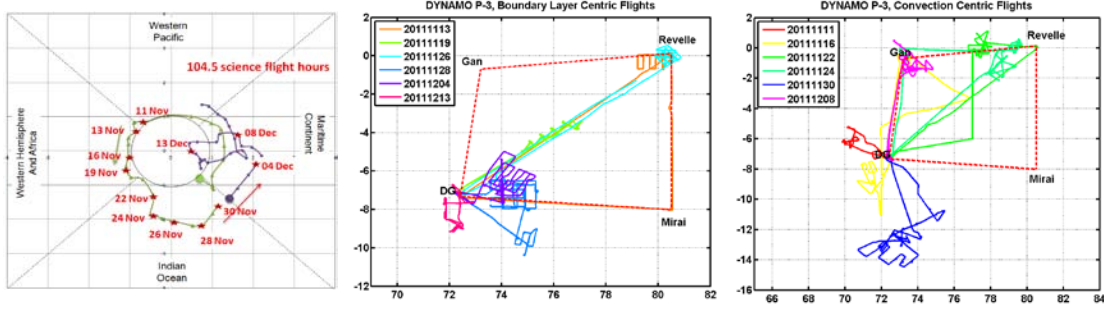
with aircraft observations. Comparison of the vertical cross sections from all flights show that both versions of COAMPS simulated a jet maximum that was higher in elevation with a broader extent of strong winds, both vertically and in distance offshore, while the magnitude of the strongest winds agree well with dropsonde data.

As a summary of subjective evaluation for multiple variable, Fig. 7 shows the normalized Taylor Diagram (Taylor 2001) for uncoupled COAMPS, uncoupled NCOM and coupled COAMPS/NCOM variables. Uncoupled COAMPS values are shown in red; uncoupled NCOM in green; and coupled COAMPS/NCOM in blue. In general, moving down and towards the observation point on the x-axis represents overall improvement. Comparison between the red/green (uncoupled COAMPS and NCOM) and the blue (COAMPS/NCOM) supports the generalization that the coupled model outperforms the uncoupled model within the confines of the GOTEX experiment. With the exception of wind speed, all variables show improvement from the uncoupled model to the coupled model, although the changes in wind stress and TKE are especially small. From uncoupled NCOM and coupled COAMPS/NCOM, the sea-surface temperature shows a similar improvement to the uncoupled COAMPS to coupled COAMPS/NCOM SST. Since the uncoupled NCOM receives the wind stress fields from uncoupled COAMPS (at a longer time interval), the improvement in NCOM wind stress is the same as from uncoupled COAMPS, which is minimal. The greatest improvements from the air-sea coupling are seen within the surface variables of air-sea temperature difference sensible heat flux, and latent heat flux. Improvements to these variables through the air-sea coupling are critical because of the important role of temperature and moisture distribution throughout the boundary layer, and the temperature structure in the upper-ocean.

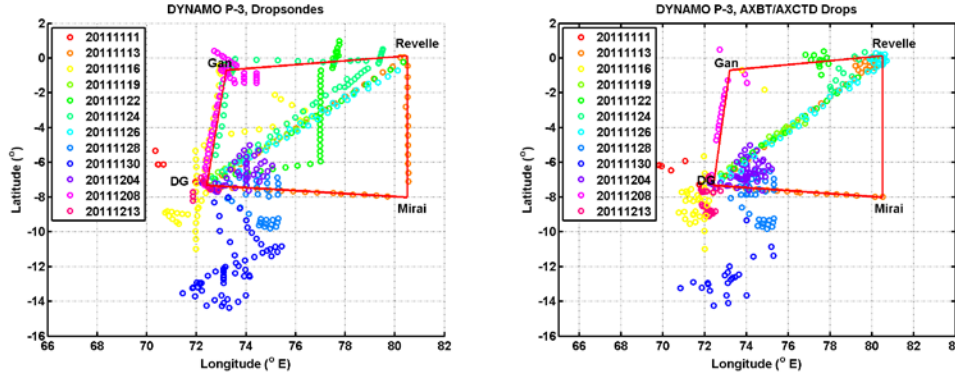


**Figure 7.** Taylor Diagram for uncoupled COAMPS (red), coupled COAMPS (blue), and coupled NCOM (green) model statistics. All statistics have been normalized according to Taylor (2001) so that the observations have a standard deviation of 1. The vertical axis represents the standard deviation of the model values (black dotted lines). The radial position represents the correlation between the model values and the observations (blue dashed lines). The centered RMS difference is represented by the green dashed lines centered on the observations.

**DYNAMO/LASP 2011 field Measurements:** NOAA P-3 made 12 flights in three stages of the MJO event in November 2011. Figure 8a below shows the individual flights relative to the MJO development. It was very fortunate that we were able to sample in all stages of this MJO event with



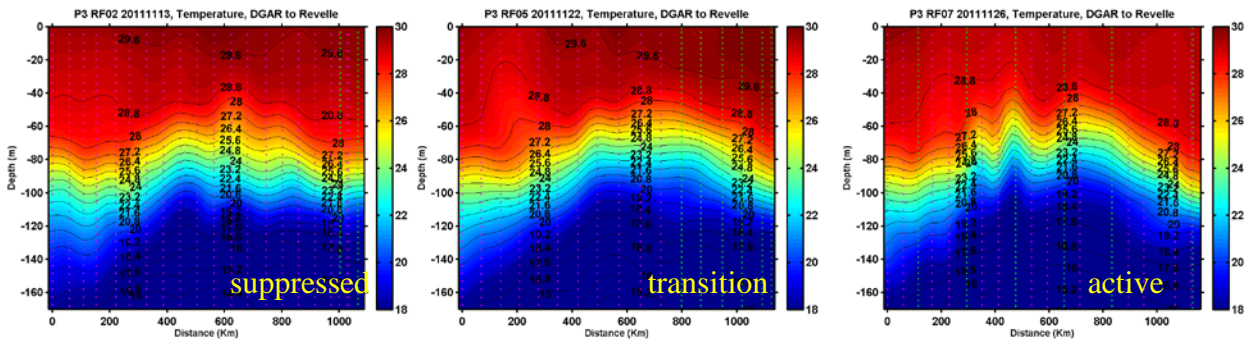
**Figure 8.** (a) DYNAMO P-3 flights in different stages of MJO denoted by the MJO phase diagram (green: November, purple: December); (b) and (c) Flight tracks for DYNAMO boundary layer centric and convection centric flights, respectively.



**Figure 9.** Date and location of DYNAMO (a) dropsondes; (b) AXBT and AXCTDs.

good coverage in each stage. Figures 8b and 8c shows the dates and location of the boundary layer centric and convection centric flights with the four corners defining the DYNAMO south array. Figure 9 shows the dates and locations of all dropsondes and AXBT/AXCTDs.

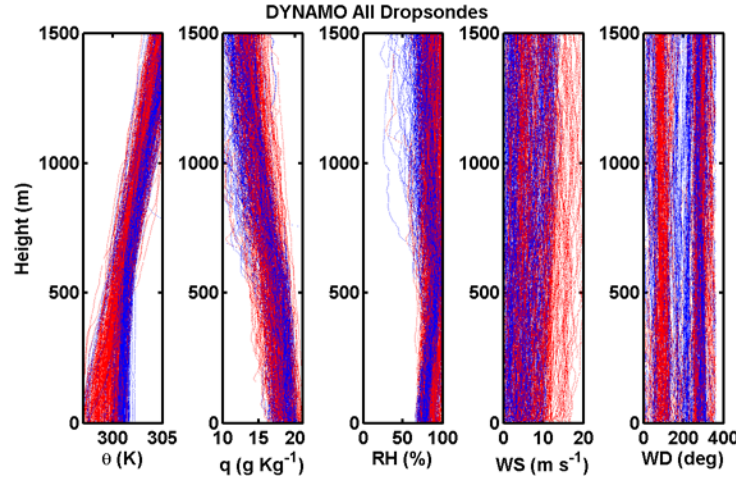
**Observed large-scale upper ocean temperature evolution:** During DYNAMO field campaign, three flights were made to the vicinity of Reville to the north east corner of the DYNAMO array, along which AXBT and AXCTDs were dropped at about 7 minute interval along the path. These upper ocean temperature profiles for all three days are shown in Fig. 10 to illustrate the evolution of upper ocean heat capacity in the upper ocean. Here, from the suppressed phase to the transition to active phase, we can see the warm up of the upper ocean on Nov. 22, 2011 (start of the MJO active phase)



**Figure 10.** Large-scale upper ocean temperature evolution from suppressed phase to active phase of MJO as seen from AXBT and AXCTD profiles. The red and green dotted vertical lines denote the location of AXBT (red) and AXCTD (green), respectively.

compared to the contour plot on Nov. 13 during the suppressed phase. The upper ocean warming is more apparent near R/V Revelle to the northeast corner where one can see that the 29.6 °C contour is at a lower layer compared to that on Nov 13. The overall cooling of the ocean mixed layers in the active phase is apparent in Fig. 10c, which may had to do with the enhanced wind speed that induced more entrainment of the cooler water to the mixed layer and/or the effect of heavy precipitation.

**Boundary layer structure and variability related to deep convection:** The presence of strong convective activities results in significant modifications to the boundary layer, one of the effects is the presence of the cold pool, an effect of precipitation evaporation. The magnitude of the 'cold pool' varies depending on the convective activities and the moisture of the convective environment. We have nominally categorized all DYNAMO dropsonde soundings based on the location and the visible satellite cloud imageries at the time of dropsonde release. Those that were released under large patches of deep clouds are labeled 'convection', and those in relatively clear region 'non-convection'. Figure 11 shows the comparisons of temperature and specific humidity between the two categories. The non-convection cases generally have a well-mixed boundary layer of about 600 m, while the soundings under convection are generally colder and more likely to be stably stratified in the lower several hundred meters. The difference of the two provides a general idea of the magnitude of the cold pool over the tropical Indian Ocean, which is in general less than 5°C. We can also see that the boundary layers were in general saturated in the convection cases, consistent with the presence of precipitation evaporation. In contrast, in the non-convective case, the relative humidity is between 65-85% in lower 300 meters.

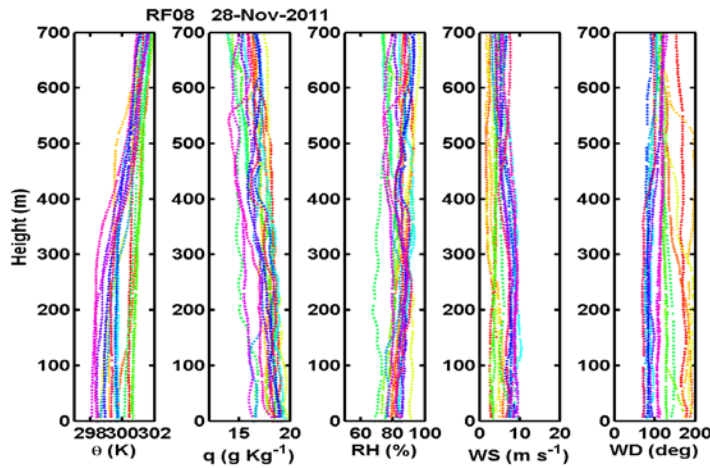


**Figure 11.** Dropsonde profiles of potential temperature, specific humidity, relative humidity, wind speed and wind direction in convection (red) and non-convection conditions.

Figure 12 shows the variability of the boundary layer within a 150 km × 150 km region under convective activities sampled on Nov. 28, 2011. We also found significant variability in wind speed and direction in addition to thermodynamic quantities. Further ongoing investigation of the spatial distribution of these sounding profiles suggests spatially coherent patterns associated with the convective activities.

## IMPACT/APPLICATIONS

The study on the gap outflow for the first time reveals the large spatial variability within the gap outflow region in both the atmosphere and the upper ocean. It also presents numerical simulations and



**Figure 12.** *Spatial variability of the boundary layer under influence of tropical convection on Nov 28, 2011.*

evaluations of the gap outflow region using the coupled COAMPS/NCOM. Results from this study contribute to further understanding of air-sea coupling process in moderate to high wind condition and the performance of coupled models.

DYNAMO/LASP measurements from the NOAA generated a comprehensive dataset in the tropical atmosphere and ocean. With the advantage of a long-range airplane and the availability of airborne expendable, the DYNAMO/LASP P-3 measurements provide valuable concurrent measurements of the atmosphere, the surface, and the upper ocean for future analyses on coupled air-sea processes and issues in air-sea coupling on different time scales.

As a result of the NRL effort in this project, the directly measured and derived solar and IR heating rate profiles obtained on this project provide a unique dataset that has the potential of directly characterizing the role of solar and IR radiative energy on the initiation and evolution of the MJO.

## TRANSITIONS

The results of the GOTEX work presented in this report provide a comprehensive evaluation of coupled COAMPS/NCOM with measurements in both the atmosphere and the upper ocean. Such evaluation provides a valuable assessment of the performance of the coupled model for operational use.

## RELATED PROJECTS

Related project is the ONR DYNAMO/LASP DRI on improvements of coupled modeling.

## REFERENCES

- McCreary, J. P., H. S. Lee, and D. B. Enfield, 1989: The response of the coastal ocean to strong offshore winds: With application to circulation in the Gulfs of Tehuantepec and Papagayo. *J. Mar. Res.*, **47**, 81–109.
- Steenburgh, W. J., D. M. Schultz, and B. A. Colle, 1998: The Structure and Evolution of Gap Outflow over the Gulf of Tehuantepec, Mexico. *Mon. Wea. Rev.*, **126**, 2673–2691.

Taylor, K. E., 2001: Summarizing multiple aspects of model performance in a single diagram. *J. Geophys. Res.*, **106**, 7183–7192.

## **PUBLICATIONS**

- Hornick, Heather R., 2012: Evolution of Atmosphere and Ocean Boundary Layers From Aircraft Observations and Coupled COAMSP/NCOM, Ph. D Dissertation, Naval Postgraduate School, Monterey, CA, September, 2012.
- Trampp, David A., 2012: Upper Ocean Characteristics in the Tropical Indian Ocean from AXBT and AXCTD Measurements, M.S. Thesis, Naval Postgraduate School, Monterey, CA, March, 2012.